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A TECHNO-ECONOMIC STUDY ON PAPER INDUSTRY WASTE- HYPO SLUDGE CONCRETE IN RIGID PAVEMENT

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ABSTRACT

Worldwide consumption of paper has risen by 400% in the past 40 years, with 35% of harvested trees being used for paper manufacture. Logging of old growth forests accounts for less than 10% of wood pulp, but is one of the most controversial issues. Plantation forest, from where the majority of wood for pulping is obtained, is generally a monoculture and this raises concerns over the ecological effects of the practice. However its utilization in cement concrete as a partial replacement of cement as well as an additive provides an environmentally consistent way of its disposal and reuse. In the present research work, hypo sludgeis used in the design of cement concrete road pavement. Pavement is a specific application of concrete designed which uses its flexural strength.

This research work describes the feasibility of using the paper industry waste in concrete production as partial replacement of cement. The cement has been replaced by hypo sludge accordingly in the range of 0%, 10%, 20%, 30% and 40% by weight of cement for the M-40 mix. Concrete mixtures were produced, tested and compared in terms of flexural strength with the conventional concrete. These tests were carried out to evaluate the mechanical properties for the test results for flexural strength up to 90 days are taken. It is observed that replacement of cement in any proportion lowers the flexural strength of concrete as well as delays its hardening. Using the characteristic flexural strengths of various hypo sludge concretes a section of road pavement is designed. Cost of sections is estimated. The economic analysis shows that replacement up to certain proportion makes the overall design economical. This provides an environmental friendly method of hypo sludge disposal.

KEYWORDS: Hypo Sludge, Rigid Pavement, Flexural Strength, Techno, Economic

INTRODUCTION

Hypo sludge consumes a large percentage of local landfill space for each and every year. Worse yet, some of the wastes are land spread on cropland as a disposal technique, raising concerns about trace contaminants building up in soil or running off into area lakes and streams. Some companies burn their sludge in incinerators, contributing to our serious air pollution problems. To reduce disposal and pollution problems emanating from these industrial wastes, it is most essential to develop profitable building materials from them.

To save energy and to earn carbon credit is very much essential for the betterment of mankind. To produce 1 tons of Ordinary Portland Cement manufacturers use earth resources like limestone, etc and during manufacturing of 1 t of Ordinary Portland Cement an equal amount of carbon-dioxide is released into the atmosphere which is harmful to the environment. Energy plays an important role in era of developing countries like India. By earning carbon credit by using industrial waste (hypo sludge) for Building Materials like cement, the energy and environment can be saved.

To produce low cost concrete by blending various ratios of cement with hypo sludge and to reduce disposal and pollution problems due to hypo sludge it is most essential to develop profitable building materials from hypo sludge. To make good quality paper limited number of times recycled Paper fibres can be used which produces a large amount of solid waste. The innovative use of hypo sludge in concrete formulations as a supplementary cementitious material was tested as an alternative to conventional concrete.

Paper making generally produces a large amount of solid waste. Paper fibers can be recycled only a limited number of times before they become too short or weak to make high quality paper. It means that the broken, low-quality paper fibers are separated out to become waste sludge. To reduce disposal and pollution problems emanating from these industrial wastes, it is most essential to develop profitable building materials from them. Keeping this in view, investigations were undertaken to produce low cast concrete by blending various ratios of cement with hypo sludge.

This research work is concerned with the experimental investigation on strength of concrete and optimum percentage of the partial replacement by replacing cement via 10%, 20%, 30%, and 40% of Hypo Sludge. The present work is a case study for J. K. Papers mill Pvt. Ltd, plant in Tappi District. Here, hypo sludge is used in various proportions (varying from 0%, 10%, 20%, 30% and 40% by weight of cement) in cement concrete. Characteristic flexural strength of concrete is determined by casting beams of various replaced hypo sludge concrete and testing them under ‘Central point method’. This test is done to have an idea of the load at which the concrete member in bending may crack due to tension. Knowledge of flexural tension is very useful in pavement slabs and their design.

Using the experimental data, pavement section is designed. The relative cost of the pavement section with OPC as well as various proportions of hypo sludge is estimated and compared. It is observed that paper industry waste hypo sludge can be safely and economically used for pavement construction. This also provides an environmentally consistent way of hypo sludge disposal.

PROCUREMENT OF HYPO SLUDGE

The hypo sludge is procured from J. K. Papers mill Pvt. Ltd, plant. This plant is located near Songadh in Tappi District in Gujarat State.

EXPERIMENTAL WORK

Chemical Properties of Ordinary Portland Cement (OPC) and Hypo Sludge

Chemical Properties of Ordinary Portland Cement (OPC) and Hypo sludge as listed in Table 1:

Table 1: Chemical Properties of Ordinary Portland Cement (OPC) and Hypo Sludge

Chemical Properties	Ordinary Portland Cement (OPC) (Percent by Mass)	Hypo Sludge (Percent by Mass)
Silicon Dioxide (SiO_2)	21.77%	5.28%
Calcium Oxide (CaO)	57.02%	47.84%
Magnesium Oxide (MgO)	2.71%	6.41%
Sulphur Trioxide (SO_3)	2.41%	0.19%
Aluminium Oxide (Al_2O_3)	2.59%	0.09%
Ferric Oxide (Fe_2O_3)	0.65%	0.73%
Loss on Ignition	2.82%	38.26%

Characterization of Cement

The most common cement used is an Ordinary Portland Cement (OPC). The Ordinary Portland Cement of 53 grade conforming to IS:8112-1989 is being used. Specific gravity, consistency, setting, compressive strengths, etc. tests is

conducted on cement. The results are tabulated in Table 2.

Table 2: Properties of Ordinary Portland Cement (OPC)

Sr. No.	Physical Properties of Cement	Result	Requirements as Per IS:8112-1989
1	Specific gravity	3.15	3.10-3.15
2	Standard consistency (%)	28%	30-35 (%)
3	Initial setting time (minutes)	35 min	30 minutes (minimum)
4	Final setting time (minutes)	178 min	600 minutes (maximum)
5	Compressive strength- 7 days	38.49 N/mm^2	43 N/mm^2
6	Compressive strength- 28 days	52.31 N/mm^2	53 N/mm^2

Cement Hypo Sludge Mix Proportions

A concrete mix M40 grade was designed as per IS 10262:2009. The design mix proportion is shown in Table 3

Table 3: Concrete Design Mix Proportions (kg/m^3)

Concrete Mix	Concrete Design Mix Proportion (By Weight in kg)				Replacement of Cement by Hypo Sludge
	Water/Cement Ratio	Cement	Fine Aggregate	Coarse Aggregate	
A2	0.38	473.68	341.91	1419.30	-
C5	0.38	426.31	341.91	1419.30	47.37
C6	0.38	378.94	341.91	1419.30	94.74
C7	0.38	331.58	341.91	1419.30	142.10
C8	0.38	284.21	341.91	1419.30	189.47

Properties of Fresh Concrete

Table 4: Compacting Factor Test for Fresh Concrete

Concrete Mix	% Replacement of Cement by Hypo Sludge	Compacting Factor
A2	0 %	0.893
C5	10 %	0.897
C6	20 %	0.890
C7	30 %	0.882
C8	40 %	0.880

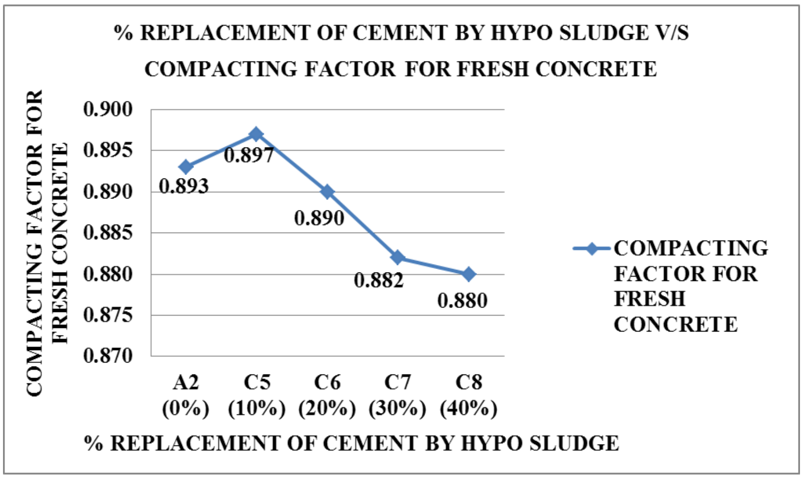

Figure 1: % Replacement of Cement by Hypo Sludge v/s Compacting Factor for Fresh Concrete

Properties of Hardened Concrete

Compressive Strength Test

Compressive strength test on 150x 150x150mm cube is done on compaction testing machine. The results at 7,14,28,56 and 90 days are presented in Table 5 and Figure 2 below.

Table 5: Average Compressive Strength for Cubes (150X150X150) (N/mm^2) at 7, 14, 28, 56 and 90 Days for M40

Concrete Mix	% Replacement of Cement by Hypo Sludge	Average Compressive Strength (N/mm^2)				
		7 Days	14 Days	28 Days	56 Days	90 Days
A2	0 %	34.81	45.04	50.81	52.89	53.93
C5	10 %	36.59	46.52	51.26	53.33	54.52
C6	20 %	34.22	39.11	40.74	42.81	43.26
C7	30 %	24.30	27.85	28.74	30.52	33.19
C8	40 %	20.36	23.26	24.00	25.19	26.52

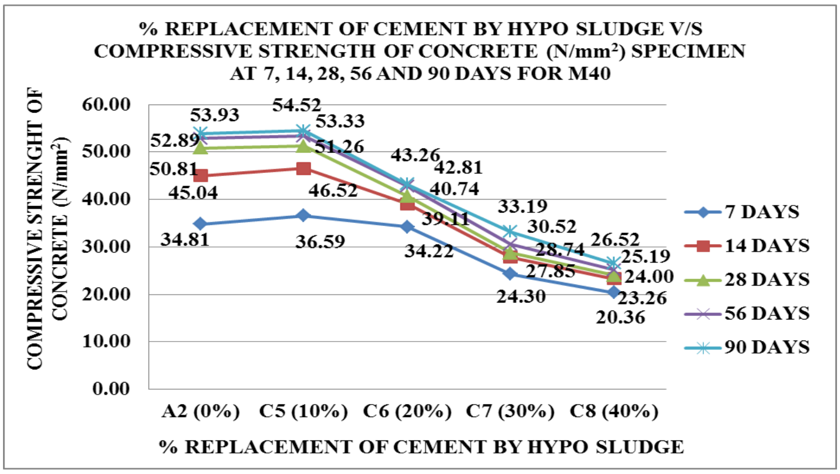

Figure 2: % Replacement of Cement by Hypo Sludge v/s Compressive Strength of Concrete (N/mm^2) Specimen at 7, 14, 28, 56 and 90 Days for M40

A table vibrator was used for compaction of the hand filled concrete cubes and cylinders. The specimens were demoulded after 24 hours and subsequently immersed in water for different age of testing. For each age three specimens were tested for the determination of average compressive strength. The test was performed on compression testing machine having capacity of 200 MT.

Split Cylinder Strength Test for Modulus of Elasticity

A split cylinder strength test was conducted for deciding modulus of elasticity of concrete. The results are presented in Table 6 and Figure 3.

Table 6: Modulus of Elasticity for Cylinders (150X300 DIA) (N/mm^2) at 28, 56 and 90 Days for M40

Concrete Mix	% Replacement of Cement by Hypo Sludge	Modulus of Elasticity (N/mm^2)		
		28 Days	56 Days	90 Days
A2	0 %	34583	35333	37417
C5	10 %	36833	37392	37500
C6	20 %	30333	31250	31917
C7	30 %	25500	25550	25833
C8	40 %	23708	24225	24333

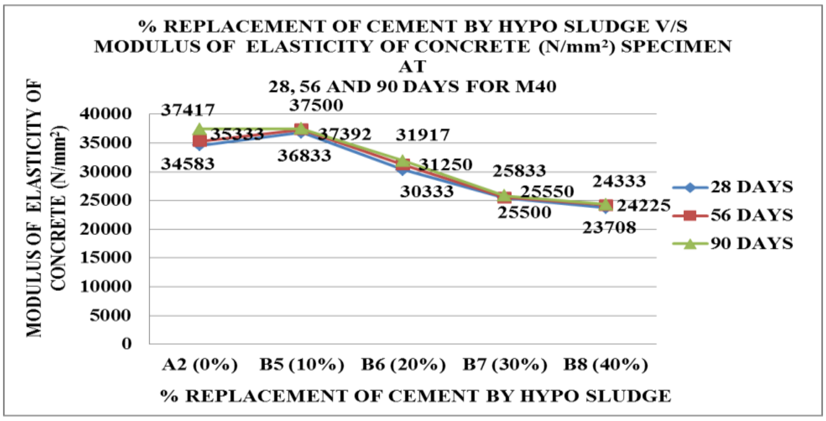

Figure 3: % Replacement of Cement by Hypo Sludge v/s Modulus of Elasticity of Concrete (N/mm^2) Specimen at 28, 56 and 90 Days for M40

Flexural Strength Test

The flexural strength is determined by the central point method. Standard metallic beam moulds (100 mm * 100 mm * 500 mm) were used for the preparation of concrete specimens for flexural strength. A table vibrator was used for compaction of hand filled concrete beams. The specimens were demoulded after 24 hours and subsequently immersed in water for different age of testing. For each age three specimens were used for the determination of average flexural strength. The test was performed on Universal Testing Machine (UTM) having capacity of 50 BT. The schematic

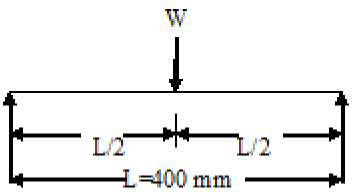

Figure 4: Schematic Representation of Loading Arrangement for Flexural Strength Test

The flexural strength is calculated by using bending equation:

$M/I = f/y$, Or, $f = M/I \times y$; Or, $f = M/Z$

Where, M, I, y and Z represent respectively bending moment, moment of inertia, distance of farthest fiber and section modulus. For rectangular section $Z = bd^2/6$. Where b and d denote the breadth and depth of the beam respectively. Here, the value of f (characteristic flexural strength is obtained experimentally and Z is calculated from beam geometry. Three specimens of beam are tested for each type of concrete and average flexural strength is obtained.

The flexural strength of concrete M40 with various % cement replaced by hypo sludge are presented in Table 7. Figure 5. It can be seen that 0% hypo sludge, i.e. concrete with no replacement of cement with hypo sludge, has maximum rate of flexural strength development as well as maximum final strength too**.** It has developed most of its flexural strength within 56 days. The rates of strength development as well as final strengths both are reduced with the addition of hypo sludge. With the increased proportion of hypo sludge concrete has lower strength at 28 days. However it keeps on gaining strength later on even up to 90 days. In long terms, concrete with higher proportions of hypo sludge gains strength which is less than that of pure concrete.

Table 7: Flexural Strength of Beam (100X100X500mm) at 28, 56 and 90 Days for M40

Concrete Mix	% Replacement of Cement by Hypo Sludge	Average Flexural Strength of Beam [N/mm^2]				
		7 Days	14 Days	28 Days	56 Days	90 Days
A2	0 %	3.62	4.27	6.10	6.95	7.46
C5	10 %	3.76	4.39	6.20	6.60	6.89
C6	20 %	2.87	3.35	4.73	4.90	4.96
C7	30 %	2.07	2.38	3.41	3.76	3.86
C8	40 %	1.61	1.89	2.70	3.07	3.19

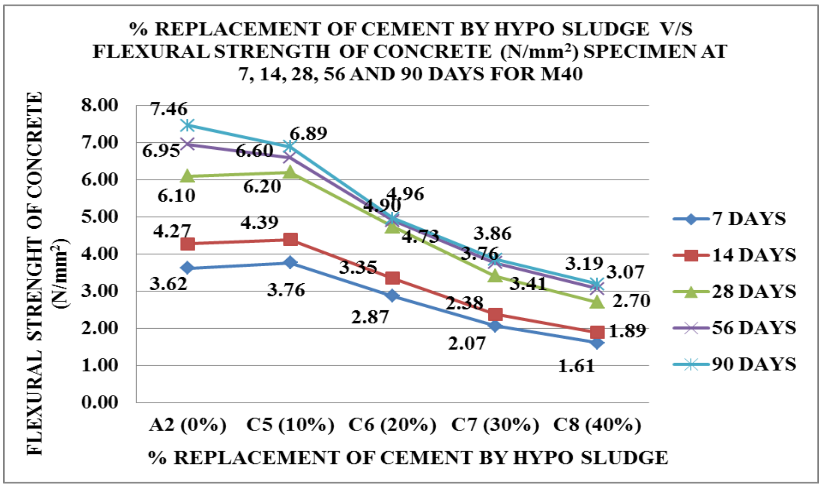

Figure 5: % Replacement of Cement by Hypo Sludge v/s Flexural Strength of Concrete (N/mm^2) Specimen at 7, 14, 28, 56 and 90 Days for M40

ECONOMIC ANALYSIS

The addition of hypo sludgereduces strength of concrete. Still there are some benefits of the hypo sludge addition. Firstly it provides an environmentally consistent way of hypo sludge disposal. Secondly in overall it reduces the cost of the structural element. Of course due to lesser strength of hypo sludge blended concrete, sectional area of structural element required will be more. But, addition of fly ash shall reduce the quantity of cement required and hence the overall cost. The effect on the overall cost of the structural element can be analyzed by taking an example. In the subsequent section, concrete road pavement is designed using various blend of cement-hypo sludge and their cost is estimated.

The cement concrete road pavement methodology is given in **APPENDIX-I** using concrete with 10% replaced by hypo sludge.

Rate of Basic Materials

The prevailing market rate gives cost on materials per kg as given Table 8.

Table 8: Costs of Materials

Sr. No.	Materials	Rate (Rs/Kg)
1	Cement (OPC 53 grade)	6.40
2	Hypo sludge	0.60
3	Fine aggregate	0.60
4	Coarse aggregate	0.65
5	Grit	0.65

Total Cost and Change in Cost of Concrete

The cost of concrete with various percentage replacement of cement by hypo sludge is computed for 1m^3 of

concrete. As hypo sludge increases cost decreases. The results are given in Table 9.

Table 9: Materials for Designed for M40 Concrete

Concrete Mix	% Reduction in Cement by Hypo Sludge	Designed Materials for Concrete					Total Cost [m^3]	% Change in Cost
		Cement [kg/m^3]	Fine Aggregate [kg/m^3]	Coarse Aggregate [kg/m^3]	Grit [kg/m^3]	Hypo Sludge [kg/m^3]		
A2	0 %	473.68	341.91	751.14	500.76	-	4159.24	0
C5	10 %	426.31	341.91	851.58	567.72	47.37	3884.50	(-) 6.60
C6	20 %	378.94	341.91	851.58	567.72	94.74	3609.75	(-) 13.21
C7	30 %	331.58	341.91	851.58	567.72	142.10	3335.06	(-) 19.81
C8	40 %	284.21	341.91	851.58	567.72	189.47	3060.32	(-) 26.42

Cost of Rigid Pavement Slab

The pavement is designed as described in Appendix-I. For concrete C8 the pavement design fails hence data is not provided in Table 10. The thickness design data for various traffics is given for concrete A2, C5, C6 and C7.

Table 10: % Replacement of Cement by Hypo Sludge and 2% CBR- 100 DLC- 90 Days with Different CVPD V/S Slab Thickness (mm)

2% CBR- 100 DLC- 90DAYS										
CVPD	**500**	**600**	**700**	**800**	**900**	**1000**	**1200**	**1500**	**2000**	**3000**
A2	220	220	230	230	230	230	230	230	240	240
C5	240	240	240	240	240	240	240	250	250	250
C6	300	300	300	300	310	310	310	310	310	320
C7	350	360	360	360	360	360	-	-	-	-
C8	-	-	-	-	-	-	-	-	-	-

For subgrade CBR=2% and DLC of 100mm thickness, the cost of 1m x1m concrete pavement is given in Table 11 and traffic v/s cost relation is shown in Figure 6.

Table 11: Different CVPD with Cost of Rigid Pavement

Description	A2	C5	C6	C7
Cement Replacement	**0%**	**10%**	**20%**	**10%**
CBR	**2%**	**2%**	**2%**	**2%**
Dry Lean Concrete (DLC), mm	**100**	**100**	**100**	**100**
CVPD	**500**	**500**	**500**	**500**
Thickness of Slab, m	0.22	0.24	0.30	0.35
Cost of 1m x 1m Slab (Rs./sq.m.)	915.03	932.28	1082.93	1167.27
CVPD	**600**	**600**	**600**	**600**
Thickness of Slab, m	0.22	0.24	0.30	0.36
Cost of 1m x 1m Slab (Rs./sq.m.)	915.03	932.28	1082.93	1200.62
CVPD	**700**	**700**	**700**	**700**
Thickness of Slab, m	0.23	0.24	0.30	0.36
Cost of 1m x 1m Slab (Rs./sq.m.)	956.63	932.28	1082.93	1200.62
CVPD	**800**	**800**	**800**	**800**
Thickness of Slab, m	0.23	0.24	0.30	0.36
Cost of 1m x 1m Slab (Rs./sq.m.)	956.63	932.28	1082.93	1200.62
CVPD	**900**	**900**	**900**	**900**
Thickness of Slab, m	0.23	0.24	0.31	0.36
Cost of 1m x 1m Slab (Rs./sq.m.)	956.63	932.28	1119.02	1200.62
CVPD	**1000**	**1000**	**1000**	**1000**
Thickness of Slab, m	0.23	0.24	0.31	0.36
Cost of 1m x 1m Slab (Rs./sq.m.)	956.63	932.28	1119.02	1200.62
CVPD	**1200**	**1200**	**1200**	**1200**
Thickness of Slab, m	0.23	0.24	0.31	-

Table 11: Contd.,

Cost of 1m x 1m Slab (Rs./sq.m.)	956.63	932.28	1119.02	-
CVPD	**1500**	**1500**	**1500**	**1500**
Thickness of Slab, m	0.23	0.25	0.31	-
Cost of 1m x 1m Slab (Rs./sq.m.)	956.63	971.13	1119.02	-
CVPD	**2000**	**2000**	**2000**	**2000**
Thickness of Slab, m	0.24	0.25	0.31	-
Cost of 1m x 1m Slab (Rs./sq.m.)	998.22	971.13	1119.02	-
CVPD	**3000**	**3000**	**3000**	**3000**
Thickness of Slab, m	0.24	0.25	0.32	-
Cost of 1m x 1m Slab (Rs./sq.m.)	998.22	971.13	1155.12	-

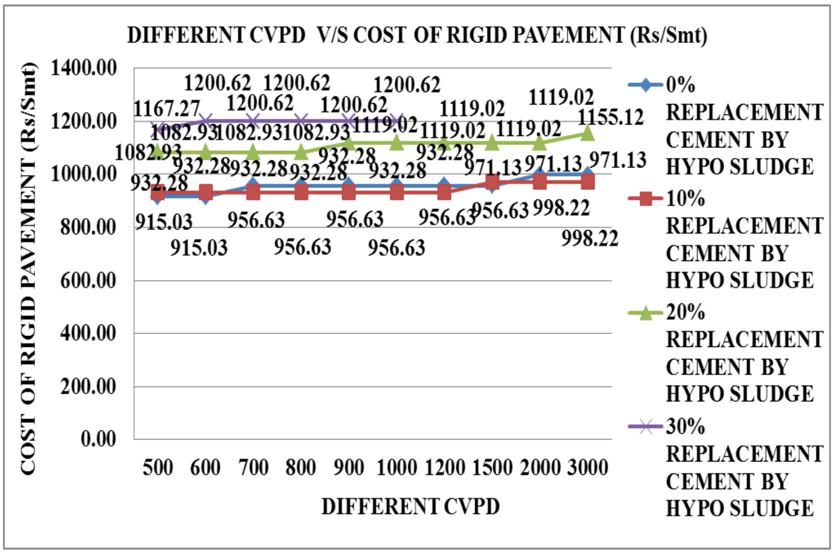

Figure 6: Different CVPD V/S Cost of Rigid Pavement (Rs/Smt)

CONCLUSIONS

Based on limited experimental investigations concerning the compacting factor test, compressive strength test, modulus of elasticity, flexural strength test of concrete for rigid pavement, the following observations are made in the ray of the objectives of the study.

- Compressive strength and flexural strength of the concrete increases with a 10 % increase in hypo sludge.
- As 10% hypo sludge increases, compacting factor increases shown in Figure 1.
- 0% replacement of cement by hypo sludge with different CVPD upto 3000, CBR value 2%, DLC=100mm so Cost of rigid pavement increases from Rs. 915.03 to Rs. 998.22. Shown in Figure 6.
- 10% replacement of cement by hypo sludge with different CVPD upto 3000, CBR value 2%, DLC=100mm so Cost of rigid pavement increases from Rs. 932.28 to Rs. 971.13. Shown in Figure 6.
- 20% replacement of cement by hypo sludge with different CVPD upto 3000, CBR value 2%, DLC=100mm so Cost of rigid pavement increases from Rs. 1082.93 to Rs. 1155.12. Shown in Figure 6.
- 30% replacement of cement by hypo sludge with different CVPD upto 1000, CBR value 2%, DLC=100mm so Cost of rigid pavement increases from Rs. 1167.27 to Rs. 1200.62. Shown in Figure 6.

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APPENDICES

Appendix-I

Design of a Road Pavement (IRC: 58-2002)

A cement concrete pavement is to be designed for a two- lane two-way National Highway in Gujarat State. The total two-way traffic is 3000 commercial vehicles per day (cvpd) at the end of the construction period. Design parameters are provided in Table A-1 and the traffic axle load spectrum is given Table A-2.

Table A-1: Design of CC Pavement for Two- Lane Two-Way National Highway Types of Concrete (C5)

Present Traffic	**=3000 cvpd**
Design life	=20 yrs.
Compressive Strength (fck)	= 54.52N/mm^2 = 545.2 kg/cm^2
Flexural strength of cement concrete (Modulus of rupture)	= 6.89 N/mm^2 = 68.90 kg/cm^2
CBR	**= 2%**
Dry Lean Concrete (DLC)	**=100 mm**
Effective modulus of subgrade reaction of the DLC sub-base (k)	= 5.6 kg/cm^3
Elastic modulus of concrete (E)	= 37500N/mm^2
Poisson's ratio (μ)	= 0.15
Coefficient of thermal coefficient of concrete (α)	= 10 x 10^{-6}/°C
Tyre pressure (q)	= 8 kg/cm^2
Rate of traffic increase (r)	= 0.075
Spacing of contraction joints (L)	= 4.5m
Width of slab (b)	= 3.5m
Load safety factor (LSF)	= 1.2
Wheel load (P)	= 8000 kg
C/C distance between two tyres (S)	= 31 cm
Joint width (z)	= 2.0 cm

The axle load spectrum obtained from axle load survey is given in the following:

Table A-2: Axle Load Spectrum Obtained from Axle Load Survey

Single Axle Loads		**Tandem Axle Loads**	
Axle Load Class, Tons	**Percentage of Axle Loads**	**Axle Load Class, Tons**	**Percentage of Axle Loads**
19-21	0.6	34-38	0.3
17-19	1.5	30-34	0.3
15-17	4.8	26-30	0.6
13-15	10.8	22-26	1.8
11-13	22.0	18-22	1.5
9-11	23.3	14-18	0.5
Less than 9	30.0	Less than 14	2.0
Total	**93.0**	**Total**	**7.0**

Cumulative repetition in 20 yrs. = $\frac{365 \times A\{(1+r)^2 - 1\}}{r}$

= 47,418,626 commercial vehicles

Design traffic = 25 per cent of the total repetitions of commercial vehicles = 11,854,657

Front axles of the commercial vehicles carry much lower loads and cause small flexural stress in the concrete pavements and they need not be considered in the pavement design. Only the rear axles, both single and tandem, should be considered for the design. In the example, the total number of real axles is, therefore, 11,854,657. Assuming that the midpoint of the axle load class represents the group, the total repetitions of the single axle and tandem axle loads are as follows:

Table A-3: Total Repetitions of the Single Axle and Tandem Axle Loads

Single Axle		Tandem Axle	
Load in Tonnes	**Expected Repetitions**	**Load in Tonnes**	**Expected Repetitions**
20	71127	36	35564
18	177820	32	35564
16	569023	28	71128
14	1280303	24	213384
12	2608024	20	177820
10	27622135	16	59273
Less than 10	3556397	Less than 16	237093

Trial Thickness = 25 cm

Table A-4: Cumulative Fatigue Life

Axle Load (AL), Tonnes	AL x 1.2	Stress, kg/cm^2 from Charts	Stress Ratio	Expected Repetitions, n	Fatigue Life, N	Fatigue Life Consumed
(1)	(2)	(3)	(4)	(5)	(6)	Ratio (5) / (6)
Single Axle						
20	24.0	38.00	0.55	71128	11.90×10^4	0.60
18	21.6	34.50	0.50	177820	73.58×10^4	0.24
16	19.2	31.40	0.46	569024	24.87×10^6	0.02
14	16.8	29.80	0.43	1280303	Infinity	0.00
Tandem Axle						
36	43.2	29.00	0.42	35564	Infinity	0.00
Cumulative Fatigue Life Consumed						**0.86**

The cumulative fatigue life consumed being less than 1; the design is safe from fatigue considerations.

Check for Temperature Stresses

Edge warping stress (St_e) = $\frac{E \alpha t}{2} C$

Radius of relative stiffness (l) = 97.18 cm

(see below under corner stress)

Therefore, L/ l = 450 / 97.18 = 4.6

Bradbury's Coefficient, which can be ascertained directly from Bradbury's chart against values of L/ l and B/ l, (C) = 0.608 from figure 2. (IRC: 58-2002)

The temperature differential was taken as 14.30°C for the Gujarat region.

Edge warping stress $= \frac{E\,\alpha\,t}{2}\,C$ = 16.30 kg/cm^2

Total of temperature warping stress and the highest axle load stress = 38.00 + 16.30 = 54.30 kg/cm^2 which is less than 68.90 kg/cm^2, the flexural strength. So the pavement thickness of 25 cm is **safe** under the combined action of wheel load and temperature.

Check for Corner Stresses

Corner stress is not critical in a dowelled pavement. The corner stress can be calculated value from the following formula:

Corner stress $S_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$

The 98 percentile axle load is 16 tonnes. The wheel load, therefore, is 8 tonnes.

Radius of relative stiffness (l) = $\sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}}$ = 97.18 cm a = radius of area of contact of wheel.

Considering a single axle dual wheel,

a = $\left(\frac{P}{p\,\pi}\right)^{1/2}$

a = $0.8521 \times \frac{P}{q \times \pi} + \frac{S}{\pi}\left(\frac{P}{0.5227 \times q}\right)^{0.5}$ a = 26.52 cm

Corner stress $S_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$ = 26.15 kg/cm^2

The corner stress is less than the flexural strength of the concrete, i.e., 77.80 kg/cm^2 and the pavement thickness of 25 cm assumed is **safe**.